THE TOTAL SOLAR ECLIPSE OF 1922 SEPTEMBER 21, TOGETHER WITH A DISCUSSION AS TO THE ORIGIN OF THE SHADOW BANDS OF A TOTAL SOLAR ECLIPSE.

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ECLIPSE OF 1922 SEPTEMBER 21.

There will occur on 21st September, 1922, a total eclipse of the sun, and various scientific bodies are arranging expeditions in order to view the eclipse at several points along the narrow belt of totality. In addition to the general observation and investigation of phenomena associated with a total solar eclipse, much attention will be devoted to obtaining further evidence of the so-called "Einstein effect," *i.e.* the apparent displacement of stars near the sun's limb due to the deflection of light rays in passing through the gravitational field of the sun. The deflection to be expected according to the Einstein Relativity Theory of Gravitation is just double that given by the Newtonian Theory, but in no case does the apparent angular displacement exceed two seconds of arc, so that extreme precision in measurement is essential. In fact, the actual displacements to be measured on a photographic plate are only about one-thousandth of an inch.

The total phase of the eclipse occurs at sunrise at a point in Abyssinia near the north-east coast of Africa, the belt of totality then leaving Africa at Somaliland, passing eastwards across the Indian Ocean, and cutting through the Maldive Islands. From there the line of totality gradually assumes a more southerly trend, moving in an E.S.E. direction to Christmas Island, where the eclipse occurs at very near noon, and then to the north-west coast of Australia, entering Australia towards the southern end of the Ninety Mile Beach. The line, then bending slightly more to the east again, crosses Australia almost centrally, finally leaving the continent just to the south of Brisbane. The total phase of the eclipse occurs at sunset at a point to the north of New Zealand.

Thus it will be seen that practically the only land areas from which the total eclipse is visible are the north-east coast of Africa, certain of the Maldive Islands, Christmas Island, and the continent of Australia. At the former the eclipse occurs while the sun is still very near the horizon, and is therefore of little value for observational work, but the Maldive Islands, Christmas Island, and various localities selected along the line of totality in Australia, will provide observational sites well distributed along the belt.

Maldive Islands. It is not yet known which of the Maldive Islands will finally be selected from which to view the eclipse, but it has been suggested that the islands of Bandidu or Dambidu would probably prove most suitable for the purpose. Difficulty may be encountered in making a landing, for charts seem to indicate that most of the islands are surrounded by broad shelving reefs of coral. The eclipse will occur here about 8.10 a.m. local time, the duration of totality at Bandidu being 4^m 11^s, and the altitude of the sun about 34°. The rainfall over the islands is very irregular, and it seems impossible to forecast the weather with any degree of accuracy. Special arrangements would be necessary in order to convey a party and equipment to the Islands, but it is understood that Mr. J. Evershed, director of the Kodaikanal Observatory (India), will occupy one of the islands, where no doubt his work will include an extended series of spectroscopic observations.

Christmas Island. The eclipse occurs here at almost local noon, when the sun at an altitude of 78° is well up towards the zenith, and therefore in a position eminently suitable for photographic work. Unfortunately Christmas Island lies about 55 miles from the central line of the eclipse; in fact, it is only a little more than 10 miles within the line of the northern limit, and thus the duration of totality will be comparatively short, viz. about 3^m 17^s. The island suffers from a heavy and irregular rainfall, although September is probably the most favourable time of the year so far as weather prospects are concerned.

The British Joint Permanent Eclipse Committee has decided to occupy this island, and Mr. H. Spenser Jones and Mr. P. J. Melotte left England in February for Singapore, whence they were to be conveyed to the island in one of the Christmas Island Phosphate Company's steamers. This party will be concerned chiefly in making further determinations of the deflection of light in the gravitational field of the sun, and a 13-inch astrographic telescope, equatorially mounted, will form part of the equipment. As this instrument should be erected by May, several months will be spent in carrying out an extensive programme of photometric work with a view to standardising the photographic scales of stellar magnitude for the southern hemisphere with those of the northern. Thus even if unfavourable weather should prevail at the time of the eclipse, highly important results will yet have been obtained.

In addition to the British party, it is believed that a joint Dutch and German expedition under Prof. Voûte, of Batavia University, and Prof. Freundlich, of Germany, will also visit Christmas Island. It is possible that the personnel of this latter party will include Prof. Einstein himself.

Wallal, W.A.[1] The moon's shadow will reach Australia towards the southern end of the Ninety Mile Beach, and this region undoubtedly affords highly favourable opportunities for viewing the eclipse. Wallal, where there is a telegraph station, is only 2½ miles from the central line of the eclipse, the width of the belt of totality being about 135 miles. The entire district is one of low, rolling sand dunes, and no difficulty would be experienced in selecting an observational site almost exactly on the central line, thus securing the maximum period of totality. The weather prospects for Wallal are exceptionally good; in fact, the average rainfall on the Ninety Mile Beach for the months of August, September and October does not exceed 0.06 inches in any one month.

The Circumstances of the eclipse at Wallal (lat. 19° 46′ S., long. 120° 41′ E.) are as follows:—

		W.A. Standard Time.			
		h.	m.	s.	
First Contact	21st Sept.	0	3	11·0	p.m.
Second Contact	,,	1	27	21·9	p.m.
Greatest Phase	,,	1	30	1·3	p.m.
Third Contact	,,	1	32	40·7	p.m.
Fourth Contact	,,	2	49	54·2	p.m.

Duration of Total Phase: $5^m\ 18{\cdot}8^s$

Altitude of Sun at time of Greatest Phase: 58°

Angle from North Point of First Contact: 299½°

Angle from North Point of Last Contact: 117°

Angle from Vertex of First Contact: 129°

Angle from Vertex of Last Contact: 359°

An expedition from the Lick Observatory, California, under the direction of Prof. W. W. Campbell, the director of the Observatory, will occupy Wallal, and Dr. Adams, Government Astronomer of New Zealand, and Prof. A. D. Ross, of the University of Western Australia, will be included in the party. The members of the expedition are to be the guests of the Commonwealth Government, and the Naval Department is making all arrangements for transport,

[1]The advantages of Wallal as an observational site have been pointed out in a paper by Prof. Ross and the writer. (See *Monthly Notices* of the R.A.S., LXXXI., 3.)

etc. The party will journey to Broome by the s.s. "Charon" (sailing about 20th August), whence a small schooner has been chartered for the run to Wallal (about 200 miles). The schooner can easily beach with the tide at a point opposite Wallal, and on account of the large rise and fall of tide (28 feet at springs), waggons or bullock drays may be drawn alongside the vessel when the water recedes, and stores and equipment thus landed. No doubt assistance could be obtained from the Wallal Downs sheep station, situated within four miles from the telegraph station. The party will live under canvas, and there is an abundant supply of good fresh water.

It is understood that a local party, under the direction of Mr. Nossiter, Chief Assistant at the Perth Observatory, will also occupy a station near Wallal.

Central and Eastern Australia. The belt of totality passes across the top north-eastern corner of South Australia, and an expedition from Adelaide will observe the eclipse from Cordillo Downs station, situated in this region. The party will travel to Farina by rail, whence the journey to Cordillo Downs will take some five or six weeks by camel transport. The eclipse occurs here shortly after 3 p.m. local time, the duration of totality being about four minutes.

Farther to the east, Cunnamulla and Coongoola, Goondiwindi, Stanthorpe, and Casino are crossed in turn by the moon's shadow. Cunnamulla and Coongoola are on the same line of railway, Coongoola being almost in the centre of the belt, while Cunnamulla is some 30 miles therefrom. The total phase at these two stations occurs at about 4 p.m. local time, the sun's altitude being about 26°, and the duration of totality at Coongoola 3¾ minutes. On account of their comparative isolation there would be considerable difficulty in obtaining stores and assistance; and in dry weather the dust is usually a source of great discomfort.

At Goondiwindi and Stanthorpe, almost exactly on the central line, there would be no difficulty in obtaining stores and assistance, while electric power is also available. Both stations would furnish good observing sites and accommodation. It is understood that several expeditions from the Eastern States have decided to observe the eclipse from Goondiwindi.

Casino, in New South Wales, is only about 30 miles from the coast, and being in the centre of the tourist region is easily accessible. But the astronomical conditions are of course greatly inferior to those stations farther west. The total phase will occur at about 4·30 p.m. local time, when the sun will be very near the horizon.

The chances of rain are not great at any place along the line of totality in Australia, but cloudy weather is the more likely to be met with the nearer the eastern coast is approached. But there would appear to be little doubt that the attractions of any station to the east are considerably less than those possessed by Wallal, on the north-west coast, where the weather prospects are excellent and the astronomical conditions eminently favourable. In fact, it seems highly likely that the advantages offered by Wallal are superior, not only to those of any other station in Australia, but to those offered anywhere along the whole length of the line of totality.

SHADOW BANDS.

One of the most interesting phenomena associated with a total solar eclipse is that of the "Shadow Bands." These are long, tremulous bands of alternate light and shade, which sweep across the landscape just before and after totality. They are usually ill-defined, faint and hazy, resembling in structure the shadows cast by ripples of water on the sand beneath. A completely total eclipse is not necessary for their production, for they appear to have been first recorded at the annular eclipse of 1820, and subsequently, in the eclipse of 1870, they were observed in a region just outside the zone of totality.

As might be expected from the ill-defined nature of the shadow bands, accurate observation of them is exceedingly difficult, and no doubt accounts in a large part for the great differences and apparent contradictions in the reports which have been made of them. Some observers have noted them simply on the ground or the deck of a ship; others have seen them on a white sheet spread on the ground or on a white vertical wall; while by far the most complete equipment for their observation seems to have been prepared by Dr. M. Roso de Luna during the eclipse of 1905 at Soria (Spain), an equipment consisting of no less than six screens placed in certain definite positions.[1]

It has been suggested that the existence of these bands may be due to the optical phenomenon of diffraction, the narrow illuminated crescent of the sun just before and after totality acting as the source of light, and the dark limb of the moon being regarded as equivalent to the diffracting edge. Upon critical examination, however, this theory offers so many objections, that it may certainly be discarded. According to the diffraction hypothesis, the bands should form a regular, set pattern surrounding the moon's shadow, the form of this pattern being determined by the optical laws of diffraction. The speed of the bands across the earth's surface should, therefore, be the same as that of the main shadow. Now the minimum speed of the

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1. *Astronomische Nachrichten* 4086.

umbra is 24 miles a minute, whereas in no case have the shadow bands been observed to travel at a speed greater than one-fifth of a mile per minute; in fact, in the majority of cases the recorded speed is much less than this. Further, the direction of motion of the bands should always be the same as that of the main shadow, but this is by no means invariably found to be the case. In fact, the direction of motion before totality is not always the same as after totality, while on at least two occasions[1] two sets of bands have been simultaneously observed moving in opposition directions. This cannot be explained on the diffraction hypothesis.

Again, assuming a case of diffraction at a "straight edge," *i.e.*, that the small portion of the lunar arc visible against the bright background of the sun is straight, a simple calculation will show that three minutes before totality (the average time at which shadow bands become visible), there should be no less than some 58,000,000 bands between the observing station and the advancing edge of the main shadow. Even assuming that the bands were evenly spaced in this interval, this would give the distance from band to band as only 0.08 inches, but the bands should actually become broader and more widely spaced as the main shadow approaches, so that three minutes before totality they would appear even closer together. Practically all observers agree, however, that the actual distance apart of the bands is from two to four inches, a result incompatible with that deduced from the diffraction theory. The calculation yielding the figures quoted above is made on the assumption that the bright crescent of the sun acts as a linear or "slit" source of light, an assumption which may perhaps be questioned in view of the appreciable width of the sun's crescent. But the diffraction pattern should be quite independent of the size of the slit, except that if the slit becomes too wide the diffraction bands become so blurred as to be indistinguishable.

Another theory which has been advanced to account for the existence of shadow bands claims that these bands are the result of purely local atmospheric conditions, and are not in any way attributable to the peculiar circumstances of an eclipse, except that during an eclipse the illuminated disc of the sun is reduced to a comparatively narrow slit or band. The relative movement between two layers of air at different densities would produce ripples at their common surface, causing unequal refraction and dispersion of the light rays, and consequently shadow images of these ripples would be thrown on the surface of the earth in the same manner as ripples on the surface of water cast shadows on the sand beneath. There seems no reason to doubt that such wavelets or "ripplings" would be produced in the atmosphere, and although the ripplings as shown

1. *The Total Solar Eclipse of May, 1900 (B.A.A.), p. 166.*
The Total Solar Eclipse, 1905 (B.A.A.), p. 51.

by the clouds seem to be larger than those pictured by the shadow bands, it is highly probable that waves and ripples of all sizes are present in the atmosphere. The larger waves would no doubt give rise to shadow images so diffused and blurred as to be quite imperceptible, and thus these shadow images or bands would appear never to exceed a certain size. In fact, the larger and broader the bands, the fainter and less well defined one would expect them to be, and on the whole this seems to be borne out by the evidence of observers.

These shadow images of atmospheric ripples would be produced only when the source of light was of comparatively small dimensions, such as the narrow crescent on the sun's disc when an eclipse is near totality, for with the light coming from such an extended source as the whole of the sun's disc, the shadows would be blurred and indistinguishable. In fact, the most favourable circumstance for the production of these shadow images is when the ripples of air are parallel to the illuminated crescent of the sun, and the greater the angle between the lengthwise direction of the ripples and the line of the crescent, the fainter and less well defined would the shadows be. This then affords a feasible explanation of the fact that at some localities during an eclipse no shadow bands have been observed at all; either there were no atmospheric ripples of the right magnitude to produce images, or, what is more likely, the ripplings were not sufficiently in line with the narrow crescent of the sun.

The actual direction of motion of the shadow bands would be determined by the direction of the air current producing the atmospheric ripplings; in general, these two directions would be the same. If, however, the ripplings were caused by two consecutive strata of air, both in motion, then the direction of the ripples would be determined by the relative direction of motion of the strata, and need not be the same as that of either one. Further, it must be noted that these air currents or "drifts" may be at some height above the surface of the earth, and, therefore, need by no means be in the same direction as the wind, thus accounting for the variation often observed between the direction of the wind and the direction of the shadow bands. Again, there is no reason why the direction of the atmospheric drift should not sometimes change during totality, and thus the direction of the bands might appear reversed after totality. Moreover, there may be two or more quite distinct drifts, each giving rise to atmospheric ripplings, and thus explaining the two distinct sets of bands seen simultaneously. Finally, this hypothesis serves to explain a rather curious fact observed during the eclipses of 1900 and 1905, viz., that the "whole set of moving lines was also moving" in a perfectly definite direction.[1] Could not the air drift giving rise to the bands itself form part of a larger body of air which was also in motion? This would account satisfactorily for the appearance described.

1. The Total Solar Eclipse, 1905. (B. A. A.), p. 52.

It is interesting to note that shadow bands, similar in every way to those of a total eclipse, have been observed at sunrise and sunset, when owing to the intervention of a distant hilltop, only a small portion of the sun's disc has been visible.[1] The reduced source of light necessary for the production of shadow bands is thus obtained. As the result of a remarkable series of observations made at Aoste (Italy), during the years 1905-1906, M.Cl. Rozet has not only fully identified the shadow bands of sunrise and sunset with those of a solar eclipse, but has also shown that the general character of the bands is intimately associated with atmospheric conditions.[2] Further, M. Rozet has succeeded in obtaining shadow bands with the planets Venus, Jupiter, Mercury, and with several of the brighter stars.[3]

Thus it would appear that the weight of evidence strongly supports the theory that the shadow bands of a total eclipse are the result of local atmospheric conditions, and probably the most useful line of research would be that instituted by Miss C. O. Stevens,[4] viz., the accurate determination of the atmospheric drift both up to and after totality.

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1. *Monthly Notices* of the R.A.S., XL. 5.
2. *Comptes Rendus*, CXLII., p. 913 (1906)
3. *Comptes Rendus*, CXLVI., p. 326 (1908)
4. *The Journal of the B.A.A.*, XVI., 2.